بسم الله الرحمن الرحيم

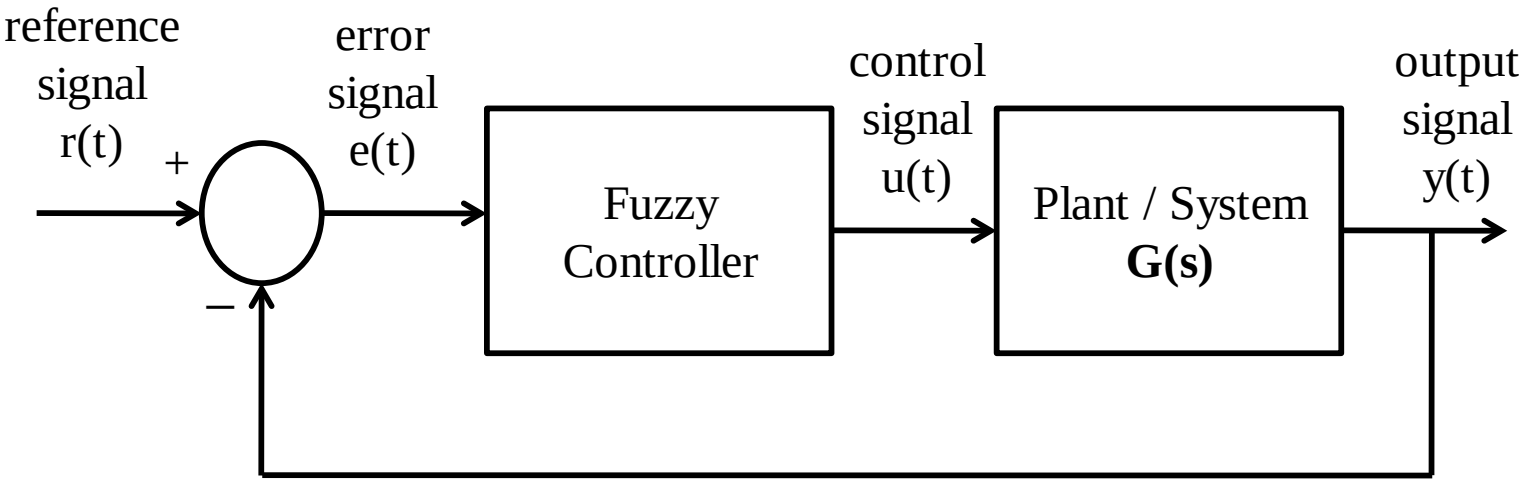
Fuzzy Control Course

Lec 3

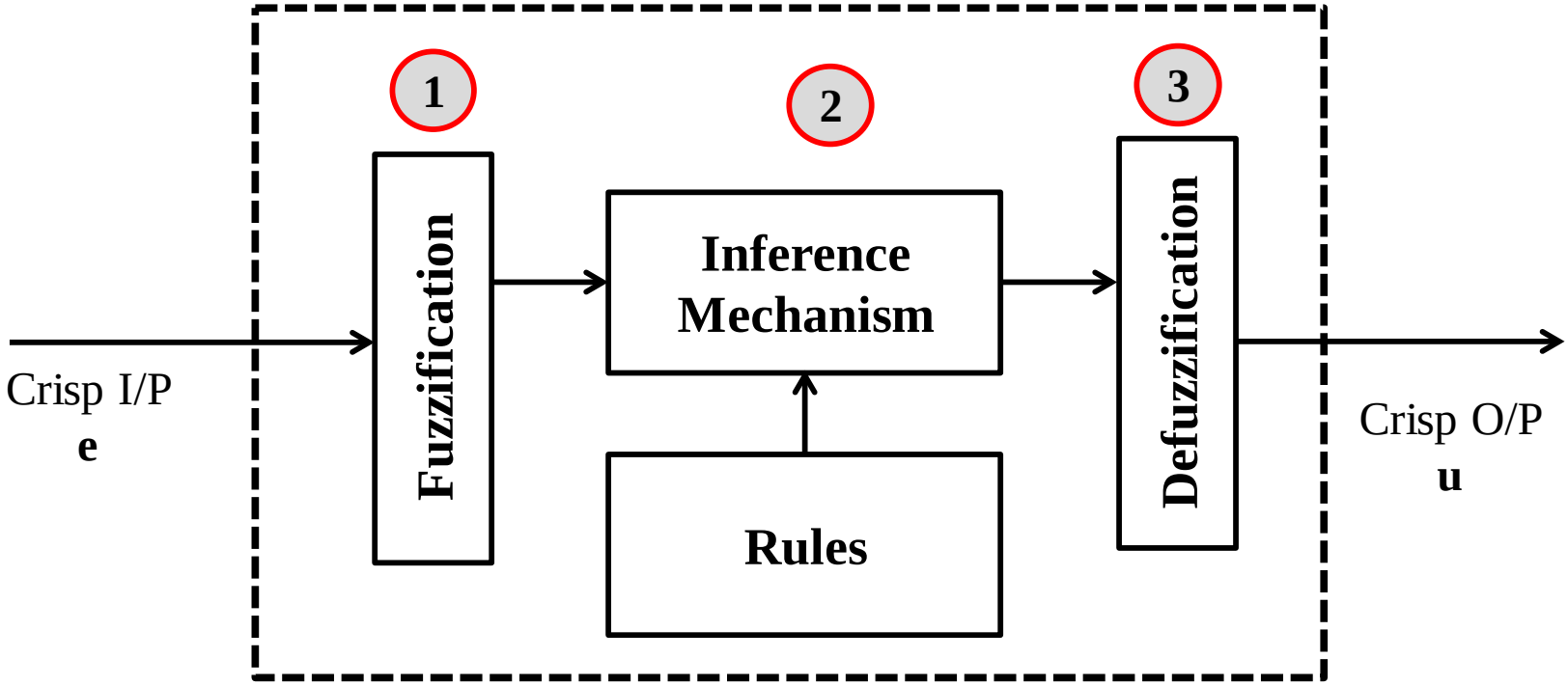
Structure of Fuzzy Controllers

DR. M. Arafa

Fuzzy Controller Structure



Fuzzy Controller Structure



Fuzzy Controller

- Crisp means numeric (or real) value

Fuzzy Controller Structure

The fuzzy controller contain three stages:

1. Fuzzification
2. Inference Mechanism
3. Defuzzification

(1) Fuzzification

- The process that allows converting crisp (or numeric) values of the fuzzy controller inputs into a fuzzy input sets.
- The fuzzification process actually provides a membership grade (μ) of a real (or crisp) value as its belongingness to a fuzzy set.

(2) Rules and Inference Mechanism

- **Rules**: is a set of IF-THEN statements including the expert's linguistic description that governs the performance of the controller.
- **Inference mechanism**: that is the heart of a fuzzy controller; which emulates the expert's decision making in interpreting and applying knowledge about how best to control the plant.

(3) Defuzzification

- Defuzzification is the inverse process of fuzzification in which a fuzzy quantity is converted into a crisp value.

Rules: Fuzzy IF-THEN Statements

- The rules are linguistic statements expressed by a human expert and are used to formulate the conditional statements that include fuzzy logic.

The general form of rules:

IF ……conditions ……..……. THEN …… actions ……

IF (or antecedent / premise) Part

THEN (or Consequent / conclusion) Part

- **IF Part**: represents the conditions to the input of the controller. For multiple conditions, AND / OR operators are used to join these conditions.
- **THEN Part**: represents the actions that apply to the output of the fuzzy controller. For multiple actions, AND / OR operators are used to join these conditions.
- The rules represent the knowledge of human experts.

Example of Fuzzy Rules

Ex1: (SISO Fuzzy controller)

- Let x and u are the speed and pressure of a steam engine. The following fuzzy controller has one input (x) and one output (u).

- Consider the input and output of the controller have two fuzzy sets:{ A1, A2} for the input x and { B1, B2} for the output u

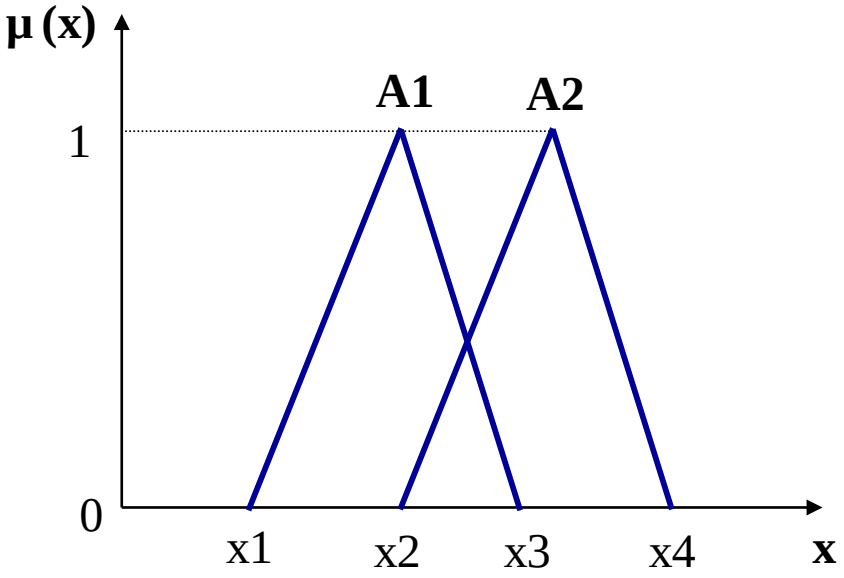
  where: A1 = slow ، A2 = fast ، B1 = low ، B2 = high

- We can use the following rules to control the pressure (u) according to the speed (x) state.

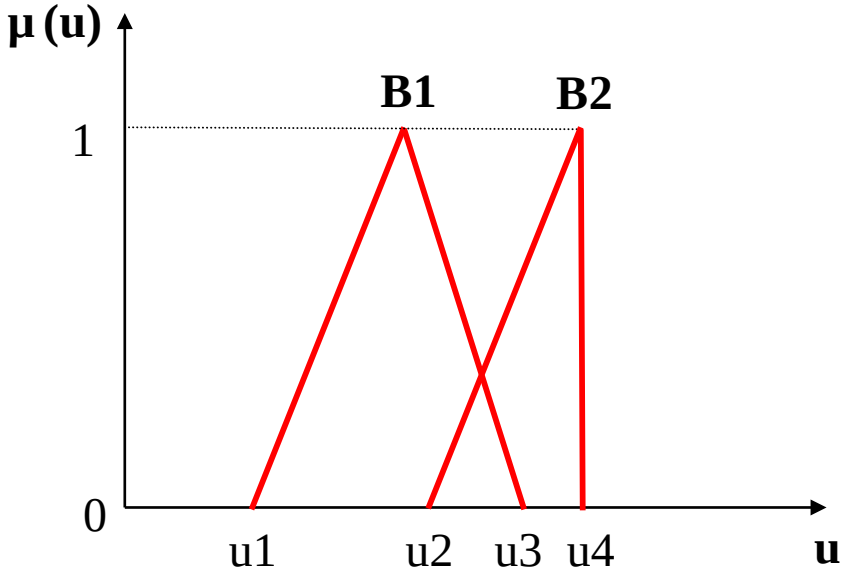
- There exist two possible rules can be written as in the following form:

R1: if x is A1 then u is B2

R2: if x is A2 then u is B1.



Membership Functions (MFs) of input x



Membership Functions (MFs) of output u

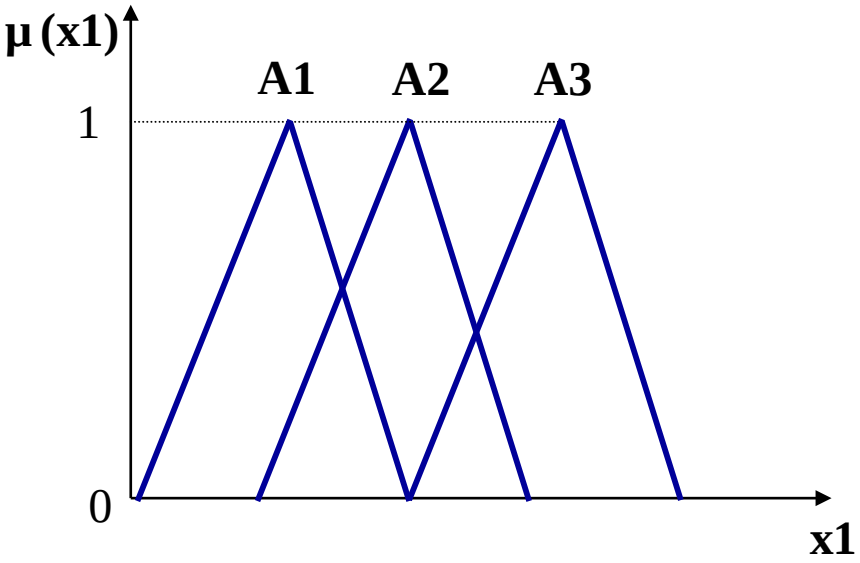
Example of Fuzzy Rules

Ex2: (MISO Fuzzy controller)

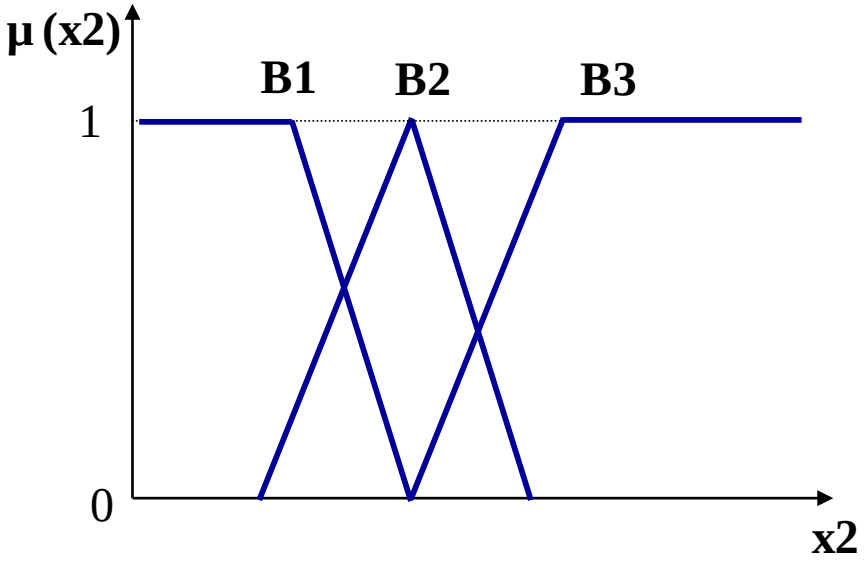
- The compound rules are used the AND / OR operators as a connective operators.
- Consider the following fuzzy controller has two inputs: x1 & x2 and one output (u).

Consider the input and output of the controller have three fuzzy sets:{ A1, A2, A3} for the input x1, { B1, B2, B3} for the input x2 and { C1, C2, C3} for the output u

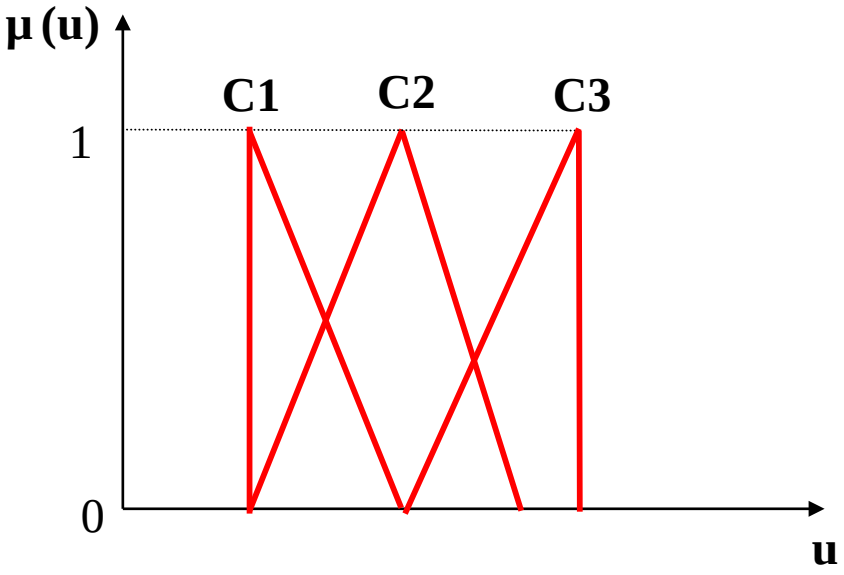
- We can use the following rules to control the output (u) according to the states of inputs x1 and x2.



Membership Functions (MFs) of input x1



Membership Functions (MFs) of input x2



Membership Functions (MFs) of output u

- There exist nine possible rules can be written as in the following form:

R1: if x1 is A1 and x2 is B1 then u is C1

R2: if x1 is A1 and x2 is B2 then u is C1

R3: if x1 is A1 and x2 is B3 then u is C2

R4: if x1 is A2 and x2 is B1 then u is C1

R5: if x1 is A2 and x2 is B2 then u is C2

R6: if x1 is A2 and x2 is B3 then u is C3

R7: if x1 is A3 and x2 is B1 then u is C2

R8: if x1 is A3 and x2 is B2 then u is C3

R9: if x1 is A3 and x2 is B3 then u is C3

- The rules can be written in a table form as in the following:

x1 \ x2	B1	B2	B3
A1	C1	C1	C2
A2	C1	C2	C3
A3	C2	C3	C3

- This table is called "**Table of Rules**".

Notes:

- The total number of rules $\leq \pi$ (The number of fuzzy sets for each input).
- Choosing the shape and no. of fuzzy sets for the inputs or outputs is based on the application by trial and error method and human experts.
- It is not necessary for the number of fuzzy sets of inputs (or outputs) to be equal.
- The most commonly fuzzy controllers are MISO (multi input-single output) with only two or three inputs.

Example of Fuzzy Rules

Ex3: (MISO Fuzzy controller)

- Write a suitable rules to design a fuzzy controller to control the level of a liquid in the tank as shown in Fig. 1.
- The inputs to the fuzzy controller are the liquid level in the tank (LV) and the rate of change in level (RC). The output of the fuzzy controller (u) control the valve position.

Consider the inputs of the controller have three fuzzy sets:{ L, N, H} for the input LV and { Ng, Z, P} for the input RC . The output of the fuzzy controller u has five fuzzy sets: { CF, CS, NC, OS, OF}. These fuzzy sets are shown in the following figures.

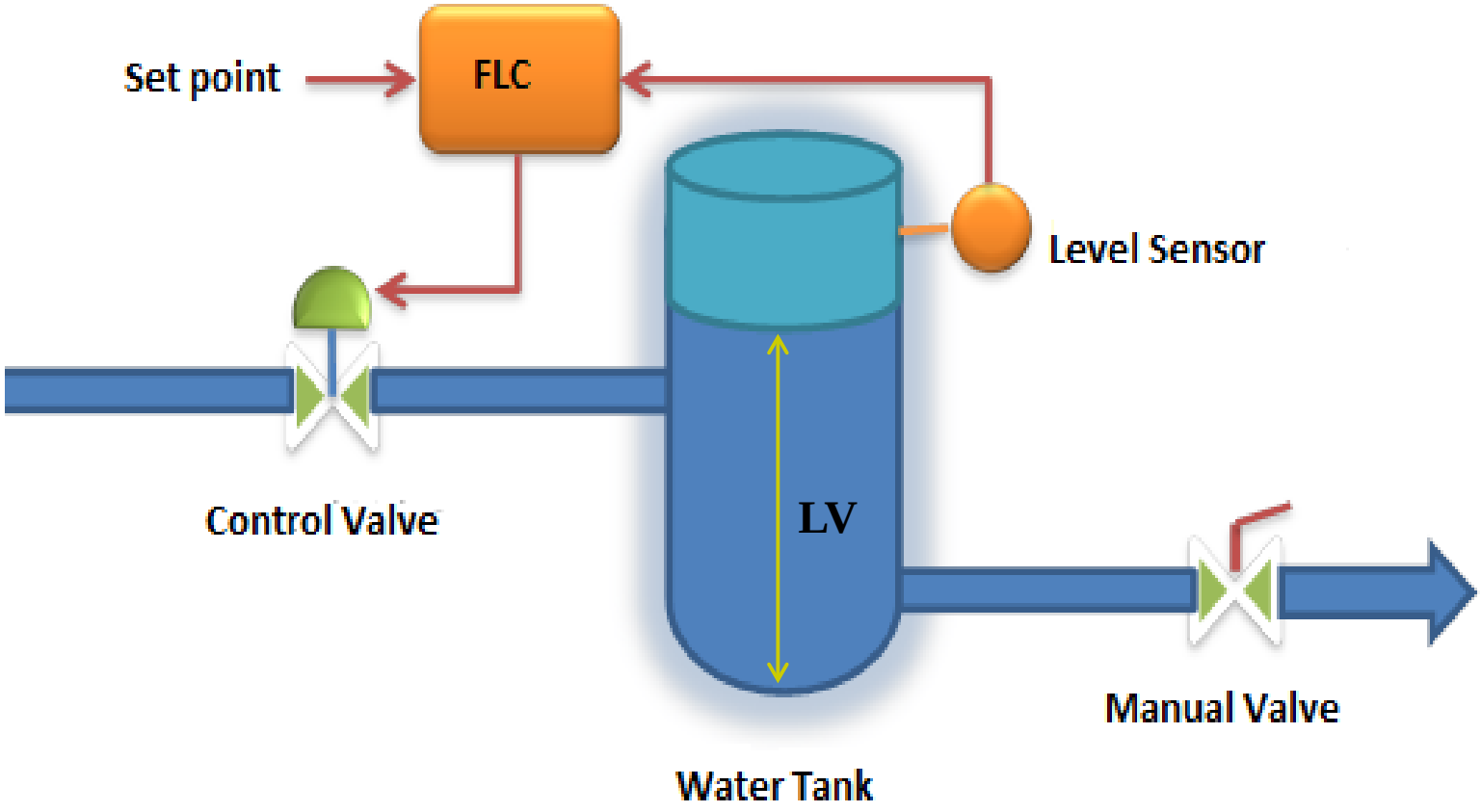
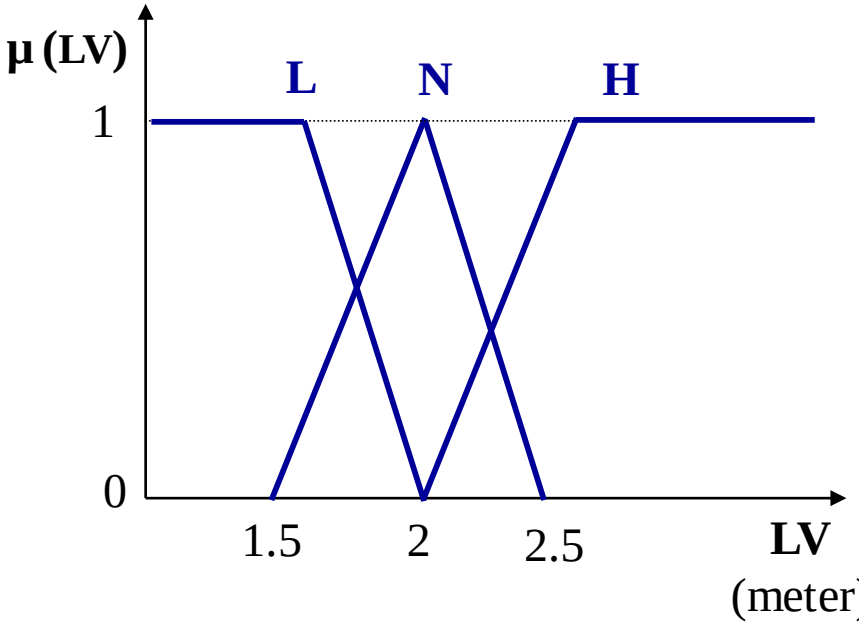
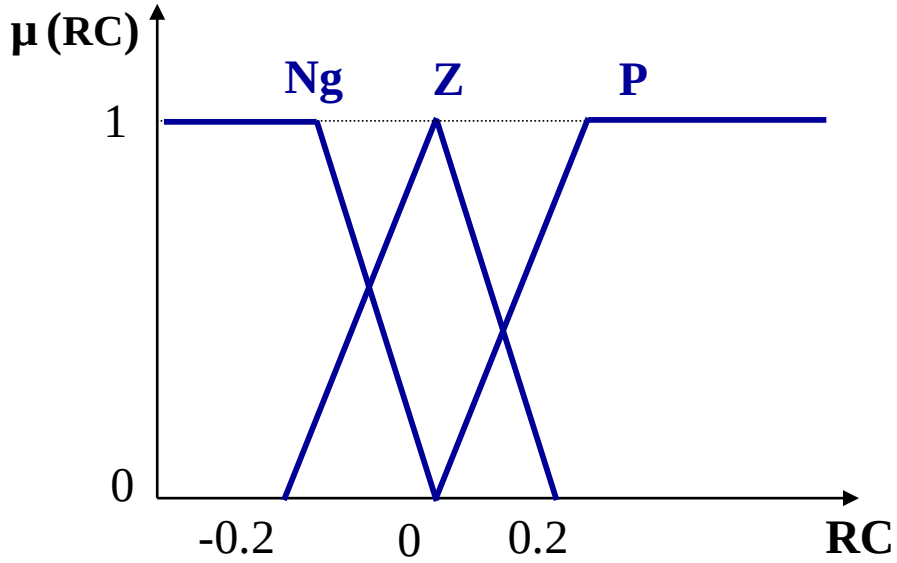
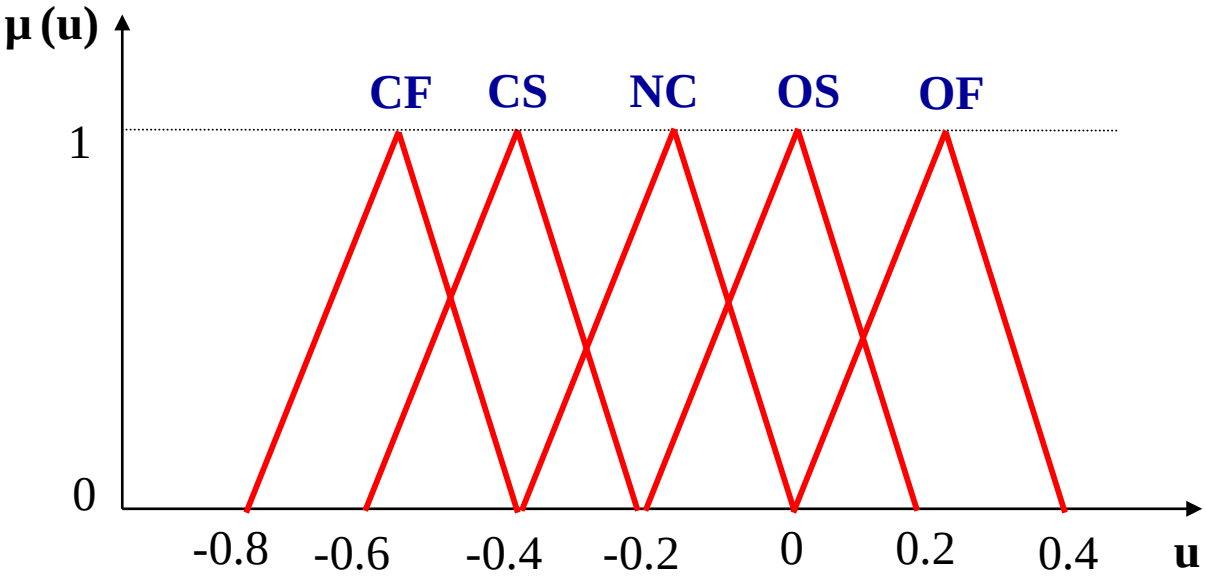


Fig. 1: Liquid level control system







L = “Low”
N = “Normal”
H = “High”
Ng = “Negative”
Z = “Zero”
P = “Positive”
CF = “Close_fast”
CS = “Close_slow”
NC = “No_change”
OS = “Open_slow”
OF = “Open_fast”

- The table of rules can be one of the following tables:

LV \ RC	Ng	Z	P
L	OF	OF	OF
N	OS	NC	CS
H	CF	CF	CF

or

LV \ RC	Ng	Z	P
L	OF	OF	OS
N	OS	NC	CS
H	CS	CF	CF

Report

- Rewrite the rules for the fuzzy controller of the pervious example if the inputs of the controller are the error (e) & change of error (Δe) and the output is u.

Where: $e = LV_{desire} - LV_{actual}$

$$\Delta e = e(t) - e(t - to)$$

- Consider the inputs of the fuzzy controller have three fuzzy sets:{ N , Z, P} where: N = Negative ، Z = Zero ، P = Positive

and The output of the fuzzy controller u has five fuzzy sets: { CF, CS, NC, OS, OF}.

The Design Steps of The Fuzzy Controller:

1) Determine the inputs and output of the fuzzy controller (FC) and also the desired (or reference) input of the system should be known.
2) Choose the shapes and universe of discourses of the fuzzy sets for inputs and output of the fuzzy controller.
3) Write the suitable set of rules according to the required control actions.

- Most of design steps for fuzzy controllers are based on trial and error method and human experts.

The Design Steps of The Fuzzy Controller:

For example, the inputs of the following fuzzy controllers are:

- The error e(t) and the change of error Δe(t) are used as inputs for the fuzzy-PD controller and fuzzy-PI controller.
- The error e(t) only is used as input for the fuzzy-P controller.

Where: $e(t) = r(t) - y(t)$

$$\Delta e(t) = e(t) - e(t-t_o)$$

r(t) is the reference (or desired) input of the system.
y(t) is the actual output of the system.
e(t) is the present error.
$e(t-t_o)$ is the last error.

The Design Steps of The Fuzzy Controller:

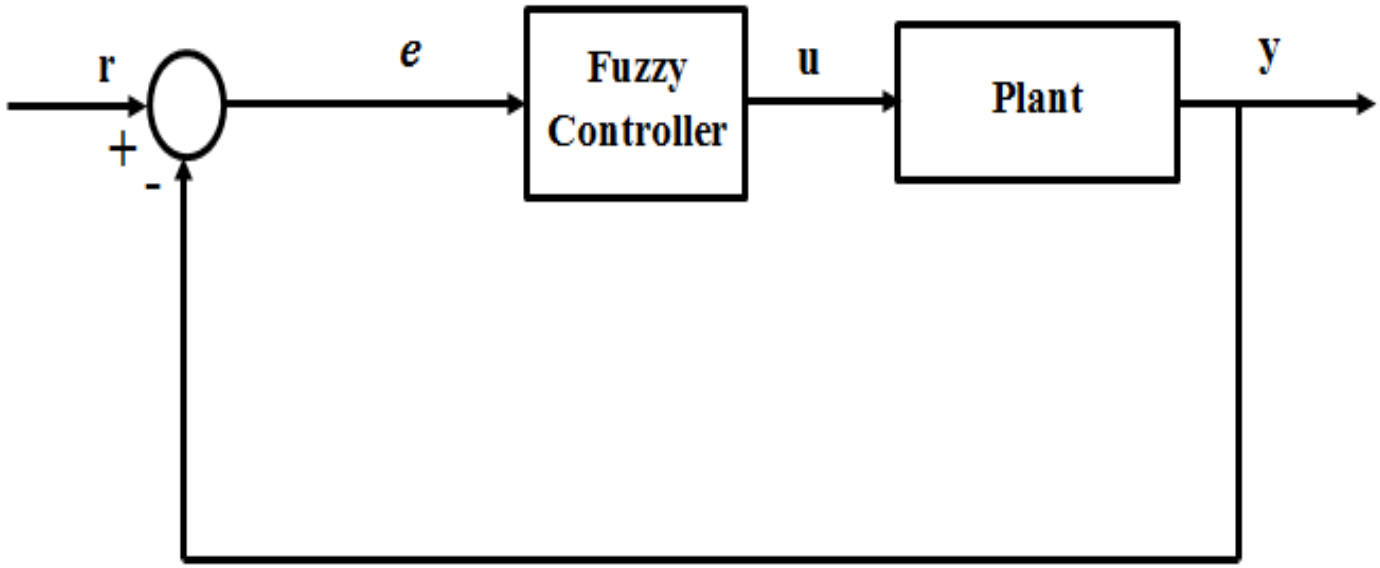
The outputs of the following fuzzy controllers are:

- The control output u(t) for the fuzzy-P controller and fuzzy-PD controller.
- The change of control output Δu(t) for the fuzzy-PI controller.

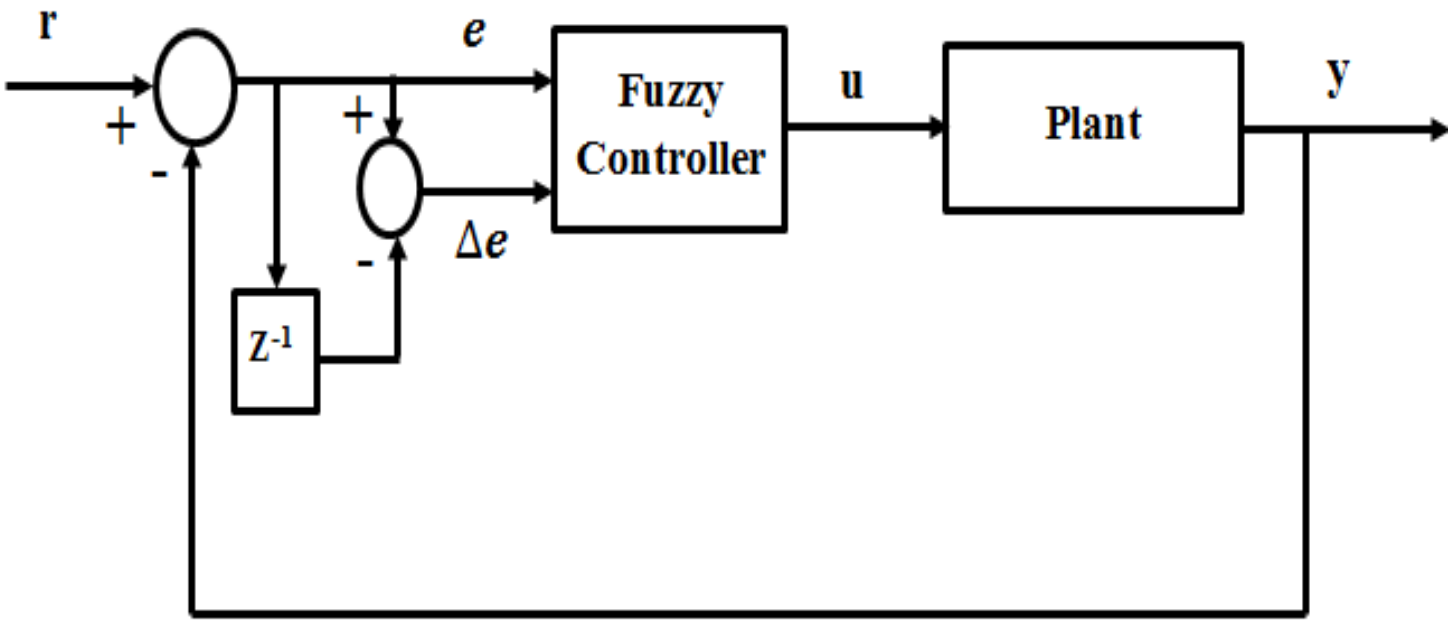
Where: $\Delta u(t) = u(t) - u(t-t_o)$

u(t) is the present control output to the plant.

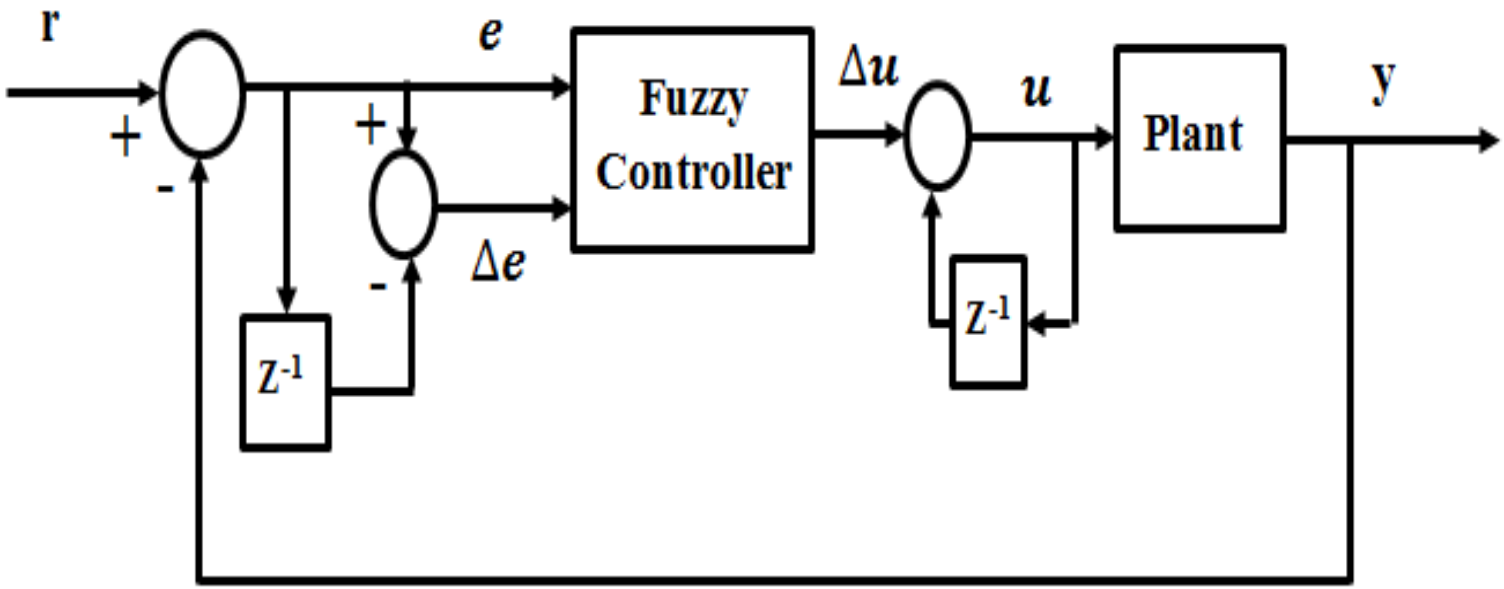
$u(t-t_o)$ is the last control output to the plant.



A closed loop system with fuzzy-P controller



A closed loop system with fuzzy-PD controller

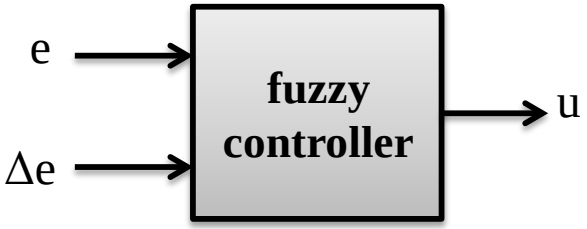


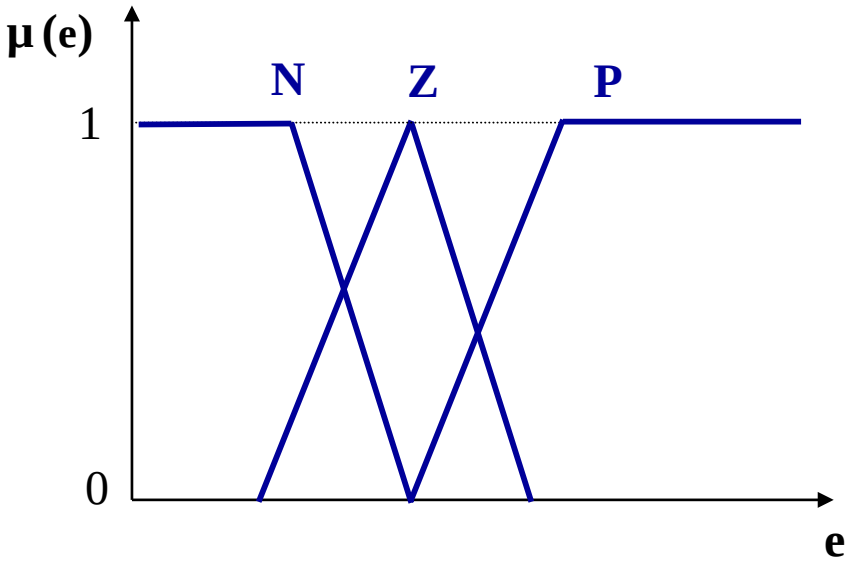
A closed loop system with fuzzy-PI controller

Note That:

- The labels of the fuzzy controllers inputs and outputs are called **linguistic variables** (Like error, speed, temperature, level, height, x1, A,……., etc.).
- The labels of the fuzzy sets for inputs and outputs of the fuzzy controllers are called **linguistic values** (Like Negative, Zero, Positive, Slow, Medium, Fast, N, P, Z, ……., etc.).

EX:





- e, Δe and u are linguistic variable.
- N, Z and P are linguistic values.